SYNTHESIZER PRIMER

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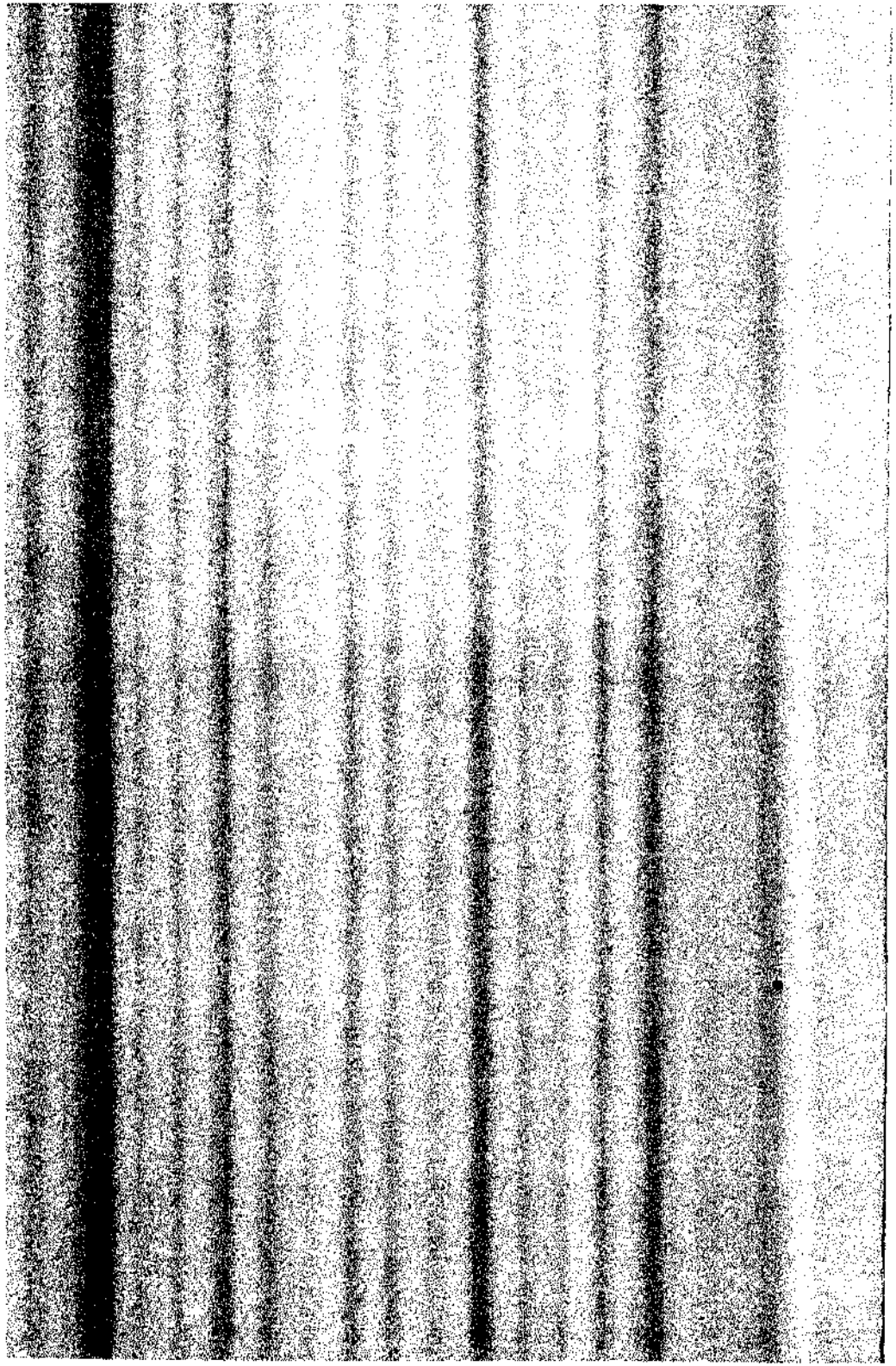


INTRODUCTION

Synthesizers have long been cloaked in mystery, mystique and misconception. It was thought one had to be an engineer to acquire even a rudimentary knowledge of this magical instrument. This is not the real case; in fact, a synthesizer is a very simple instrument.

The purpose of this booklet is to replace the mystique with understanding. The booklet begins with an introduction to the properties of sound and then relates these properties to the synthesizer's individual elements.

SOUND

There are three properties used to define any sound. They are pitch, timbre and loudness. Every sound is described by these three properties. In short every sound has a definite pitch, a recognizable timbre, and a relative loudness.

PITCH

The characteristic of sound which makes it sound "high" or "low" is called pitch. A siren is an example of a high pitched sound; thunder is a low pitched sound. A particular example of pitch is A440. A440 refers to a single pitch, the A above middle C. The 440 is the A's frequency, 440 cycles/second. The two, pitch and frequency are essentially one and the same.

The term "range" is also an important consideration when talking about pitch. A piano, for example, has a definite pitch range. It can only produce pitches between its lowest key and highest key. This span of pitches defines the piano's range. Like all instruments, the piano's pitch range is restricted to a part of our hearing range.

We can also talk about range in reference to the range of pitches people can hear, the audible range. The audible range for most people stretches from 20 to 16,000 cycles per second — almost a 10 octave range. Anything below 20 cycles we call sub-audio; and anything above 16,000 cycles is beyond our capability to hear.

Simply, pitch is the relative highness or lowness of a sound.

TIMBRE

Timbre is the quality of sound that differentiates a trumpet from a violin when both are playing the same pitch at the same loudness. The timbre is the result of "secondary" pitches being present in the sound of the respective instruments. If there are many secondary pitches present, the sound is called "bright". If there are only a few present, the sound is called "dull" or mellow.

These "secondary" pitches are usually above the basic pitch being played. These pitches are called overtones. The timbre of each

instrument is different because each instrument has its own particular pattern of overtones.

Assume both the violin and clarinet are playing the same pitch, A440. Then A440 would be called the fundamental pitch. Its symbol is f_1. The first overtone (represented by the symbol f_2) has a pitch of 880 cycles per second (2x440); the second overtone (f_3) has a frequency of 1320 cycles per second (3x440); the third overtone (f_4) of 1760 cps (4x440)1 and so on. Since the overtones are exact whole number multiples of the fundamental pitch, there isn't any beating between them.

The trumpet and violin, as we stated, have different overtones. The violin produces the fundamental (f_1) and all the odd and even numbered overtones (f_2, f_3, f_4, f_5, ... etc.). The clarinet on the other hand produces the fundamental (f_1) and the odd numbered overtones (f_3, f_5, f_7, f_9, ... etc.). Generally the overtones are not as loud as the basic pitch and are therefore not recognized as "the fundamental pitch of the sound". In fact, the loudness of the higher numbered overtones decreases rapidly.

In conclusion, every instrument has its own set of overtones that make up its timbre. The two factors that account for the difference in timbre are: which overtones are present; and the relative strength of the overtones present.

There are four basic combinations of fundamental and overtones that are important in electronic music. These specific combinations are named: sine, triangle, square, and sawtooth. A sine wave is like a flute in quality. A sine wave looks like this ∿ on an oscilloscope.

A triangle wave ⋀ consists of a fundamental and the odd numbered overtones. The overtones that produce the triangle wave are very weak in strength. The quality of the sound produced by a triangle waveform at an audible pitch is like a wooden recorder.

A square wave ⊓⊔ , like the triangle waveform consists of the fundamental and the odd numbered overtones. The overtones that make up a square wave are much stronger, much louder than the same overtones in the triangle. The square wave has a "hollow" sound to it, like a clarinet.

Lastly, the sawtooth waveform ⋀ consists of the fundamental frequency and the even and odd numbered overtones. The sawtooth sound quality is very "bright" like a string or brass instrument.

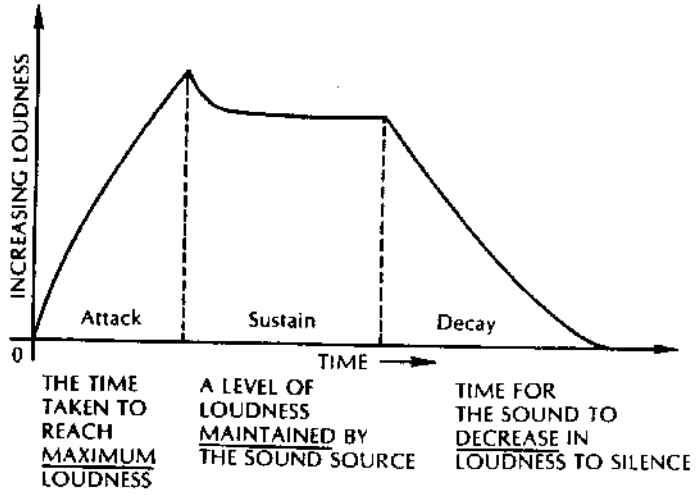
LOUDNESS

Loudness is the third property of sound. It has two important aspects. The first is overall loudness which can vary from the rustle of leaves to the blast of a rocket. The other is how the loudness of the sound changes with time. For most musical sounds the loudness versus time characteristic may be broken into three parts:

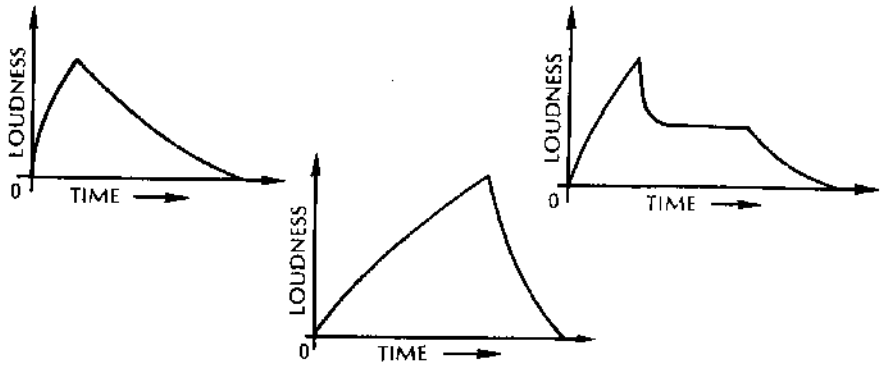
1. Attack time — the time period from silence to when the sound reaches its maximum loudness.
2. Sustain time — the period during which the sound is maintained at some loudness level.
3. Decay time — the period during which the sound fades away to silence.

A voice is an example of a sound that has flexible loudness. A sound from a voice can begin very quietly and increase in volume, then hold some volume level for a time, and finally decrease the loudness of sound until it is silent. A piano cannot do this. Once a string is struck, its variations in loudness are determined by the mechanical structure of the piano.

A graph of the variations in loudness in a typical sound is shown below.



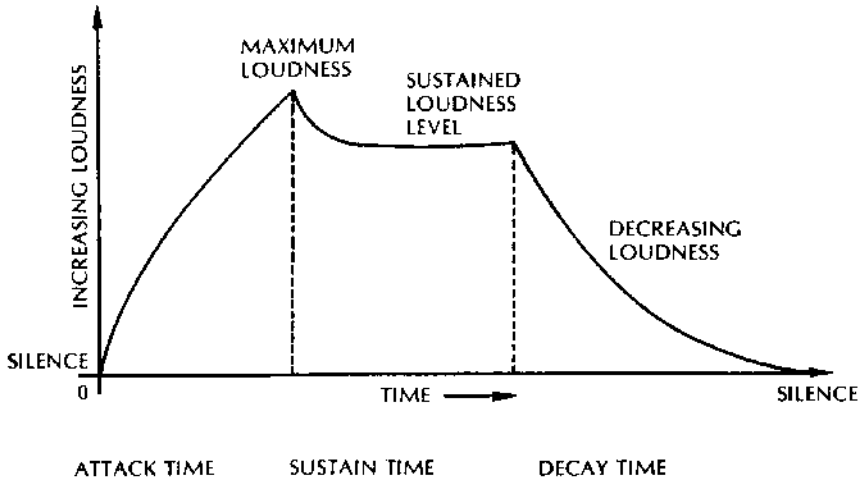
The voice has the ability to stretch or compress the three time increments in any way desired. It can instantly go to maximum loudness and take a long time to decay. Or take a long time to increase in volume, hold a loudness level for a long time and then instantly drop in volume to silence. A flexible loudness source can achieve any combination, a few graphs will give you an idea of loudness versus time possibilities.



The three time increments of loudness are collectively called the "envelope" of a sound. These increments each have a name. The time it takes for a sound to reach its maximum loudness is called the attack time. The time a sound source maintains a level of loudness is called its sustain. The time it takes a sound to decrease in loudness to silence is called the decay time.

Previously mentioned as examples of flexible and fixed envelope sources were the voice and the piano. Some other examples of instruments that have a flexible envelope other than a voice are woodwinds and brass instruments. Sound sources where loudness envelopes are fixed according to their natural characteristics are guitars, drums, harpsicord and chimes.

In summary, the loudness of a sound source is described by three time increments: attack, sustain, and decay. The attack, sustain and decay times make up a sound source's total loudness pattern called an envelope. A graph of a simple envelope is drawn below.



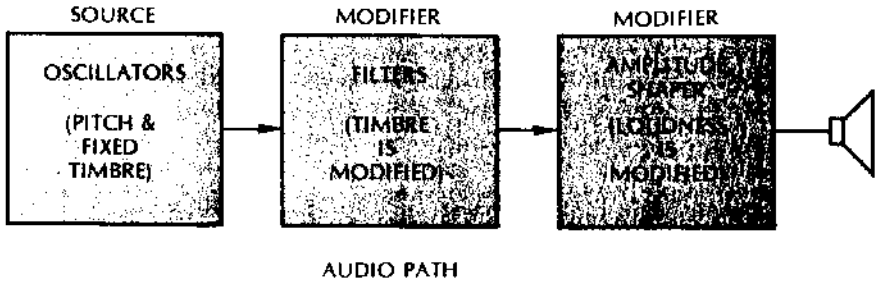
These variations in loudness are dynamic. In other words, the loudness varies during the sound. Changes in timbre and pitch can also occur during a sound and usually do. Therefore, be alert to the fact that there are pitch and timbre envelopes as well as loudness envelopes.

SYNTHESIZER FUNCTIONS AND PROPERTIES OF SOUND

The synthesizer is an instrument capable of producing almost any sound. It produces sounds with electrical circuits capable of precisely controlling the three properties of sound: pitch, timbre and loudness. Each property of sound is determined by a specific synthesizer functions.

The pitch of a sound is produced by the synthesizer's sound source, the oscillator. The oscillator produces the desired pitch with a fixed timbre (waveform). The timbre of a sound is controlled further by the synthesizer's filter. The filter modifies the timbre by changing the waveforms from the oscillator. The loudness of a sound is determined by the amplitude shaper (sometimes called a voltage controlled amplifier).

In summary, the three properties of sound are produced and controlled by the oscillator, filter and amplitude shaper. The oscillator is called the sound source since the sound begins here. The filter and amplitude shaper are called sound modifiers because they change the overtone structure and volume level of the oscillator's fixed timbre and volume. The flow of the sound from source through the modifiers is called the audio path.



The sources and modifiers comprise two of the three parts of a synthesizer. The third part of a synthesizer is the controllers. The controllers determine how (in co-operation with you) the pitch, timbre and loudness will vary.

THE BASIC SYNTHESIZER

The synthesizer is made up of three groups of functions: sources, modifiers, and controllers. The sources are where pitches of fixed timbre and loudness are produced and the range of the instrument is defined. The principle sources on synthesizers are called oscillators. The oscillators can produce any desired pitch. Their range is very great; it usually extends from a sub-audio frequency (below 20 cycles per second) to well beyond our hearing capability (over 16,000 cps). A synthesizer's range is greater than any traditional musical instrument.

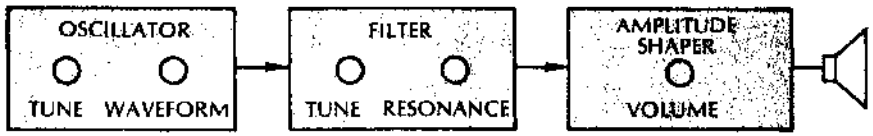
An oscillator has two controls. One adjusts the pitch up and down. This control is variously called tune, octave, pitch or frequency. The second control selects the oscillator's waveform (fixed timbre). Normally a choice of triangle, square and sawtooth waveforms is provided.

The pitch and fixed timbre produced by the oscillator then "flows" into the filter of the synthesizer. The filter is classified as a modifier. The filter takes the fixed timbre and can modify it in many ways.

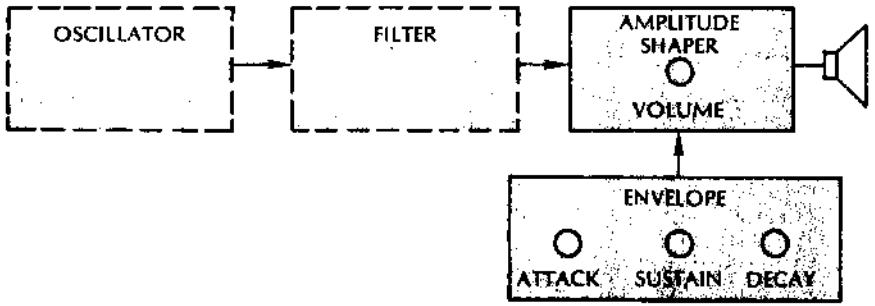
There are two controls on the filter. One is called the tune control, the other the resonance control. The tune control determines what pitches (fundamental and overtones) will pass through the filter to the amplitude shaper. For example, the filter can be set to pass only the fundamental frequency; the fundamental frequency and a select number of overtones; just a group of overtones; or even a single overtone (present in the waveform). The strength of the overtones being allowed to pass through the filter is determined by the filter's resonance control.

The filter on small synthesizers is normally a low pass filter. In other words, it concentrates on modifying the lower overtones. Larger synthesizers have high pass and band pass filters in addition to low pass. The three types of filters are related to the common bass and treble controls found on amplifiers. The bass control is similar to low pass filtering; the treble control to high pass filtering. Band pass filtering is a combination of the two.

From the filter the audio signal flows to the amplitude shaper where its total loudness pattern is determined. The amplitude shaper has a single control for determining the overall volume of the sound.



Also connected to the amplitude shaper is the envelope generator. It is a controller. The envelope generator permits dynamic variations in loudness.



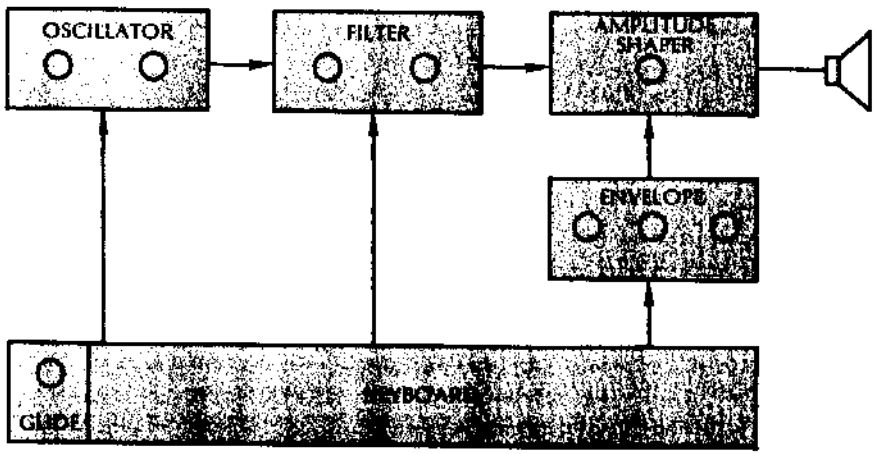
The envelope generator has three controls. These three controls are completely variable for flexible shaping of loudness. One is for the attack time of the sound; the time it takes for the sound to reach its maximum loudness level. The second is a sustain level control. This control is used to set the level of loudness you want the sound to maintain after the maximum loudness. Lastly, the envelope has a decay time control. The decay time is the time taken to get from the sustain level to silence.

When the envelope is connected to the amplitude shaper, the amplitude shaper will vary the loudness exactly as determined by the settings of the three envelope controls. The envelope starts its attack when a key is depressed on the keyboard (another controller). It completes its attack and decays to the sustain level where it stays until a key is released. When the key is released, it decays to silence.

Since the keyboard is used to initiate the envelope, it is considered to be the primary controller. As such, the keyboard performs three important jobs for each key depression: 1) it tells the oscillators which pitch to produce, 2) it tells the filters where to start filtering, and 3) tells the envelope to start its loudness pattern (attack, sustain, and decay).

Normally, each key depression on a traditional keyboard instrument results in a discrete change in pitch. However, a feature of a synthesizer keyboard is the ability to portamento or glide from one pitch to another. For example, depress a key without portamento or glide and you get that key's corresponding pitch from the oscillator; depress another key and the oscillator will instantly produce the new key's pitch without sounding the pitches in between. Using portamento, the pitch will glide sounding all the pitches between the two successively depressed keys. The portamento or glide can be adjusted for very slow or very fast glides.

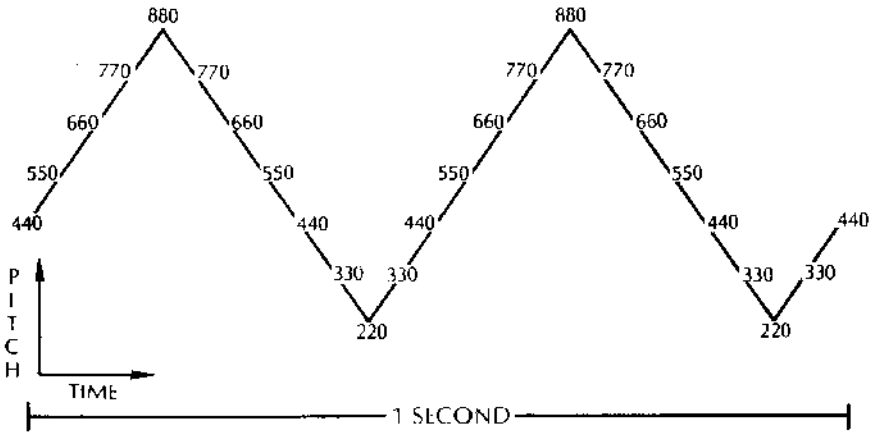
The pitch produced by the oscillator can be controlled by other controllers in addition to the keyboard. For example, a sub-audio oscillator or an envelope can be used to automatically change pitch for vibrato or special effects.



When a sub-audio oscillator (called a modulation oscillator) is applied to a source oscillator (audible oscillator), the frequency produced by the audible oscillator will increase and decrease according to the waveform and rate of the sub-audio oscillator. An example of a sound whose frequency is being changed automatically by a sub-audio oscillator is a police car siren.

To illustrate this more clearly let us use a 2 cycle per second (cps) triangle waveform (we could use a sine, sawtooth, or square also) from the modulation oscillator and apply it to the audible source oscillator. Assume that without any modulation the source oscillator is producing a 440 cps pitch. Once the modulation oscillator is connected, the pitch of the source oscillator will increase and decrease at 2 cps. This increase and decrease will follow the pattern of the modulation oscillators waveform. With the triangle waveform the pitch of the audible oscillator will increase smoothly, reach a maximum pitch and decrease smoothly to some minimum pitch at a 2 cycle rate.

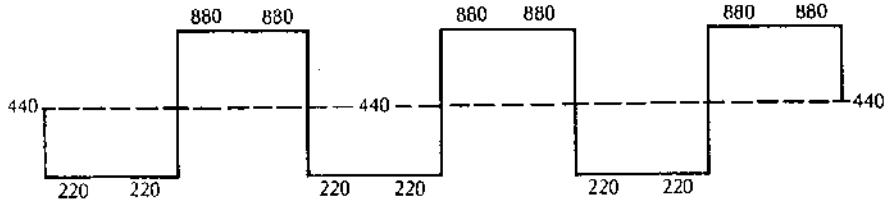
Graphically the application of the modulation oscillator results in pitch changes of this nature when using its triangle waveform.



The numbers on the graph refer to the frequencies being sounded as the triangle increases and decreases. You can see how the frequencies increase and decrease smoothly and that the resultant graph looks like the triangle waveform of the modulation oscillator. This is controlled modulation of the source oscillator.

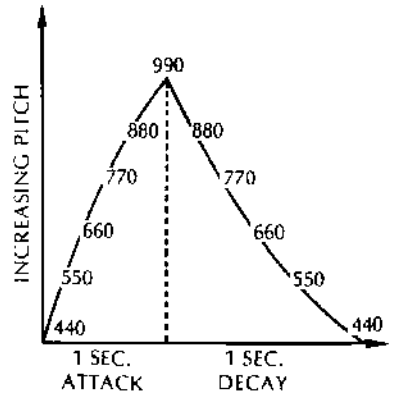
In the pictured example the pitch is increasing and decreasing by exactly one octave about A440. The amount of increase and decrease is controllable and may be varied from a small part of a semi-tone to octaves. If we apply the modulation oscillator to a greater degree, the resultant pitch change will be greater. If we reduce the amount of application, the pitch changes of the source oscillator will be smaller. If we speed up or slow down the modulation oscillator, we correspondingly effect the rate of change of the source oscillator.

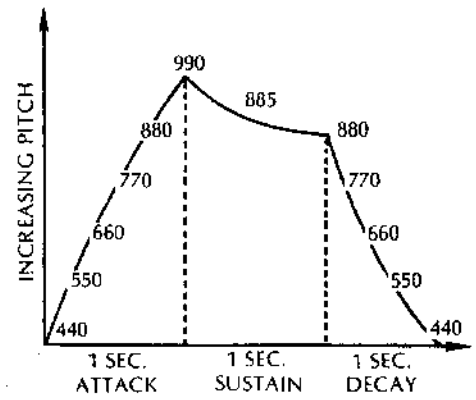
Of course, other modulation oscillator waveforms would produce different results as shown by the square wave below.



An envelope can also be used to control the source oscillator's pitch. Again, as in the case of using a modulation oscillator, the more you apply the envelope, the greater the pitch change of the source oscillator. The pitch change will exactly follow the shape of the envelope just as it followed the waveform of the modulation oscillator.

During the attack time of the envelope, the pitch of the audio oscillator will increase to some maximum pitch. The sustain level will hold some pitch and the decay time will bring the pitch back down to the pitch of the key depressed. The longer the attack, the longer the time it will take for the pitch to increase. The amount of time the sustain level will hold the pitch is determined by how long the key is depressed. And lastly, the longer the decay time, the more time it will take for the pitch to decrease to the pitch that corresponds to the key depressed. A graph of this is shown below. The first graph uses an envelope with a 1 second attack and decay time. The second graph uses the same 1 second attack time and decay times, but with a sustain level added to show the resultant pitch changes. Again, the source oscillator has been assumed to be starting at A440. Of course, the amount of envelope application is variable.



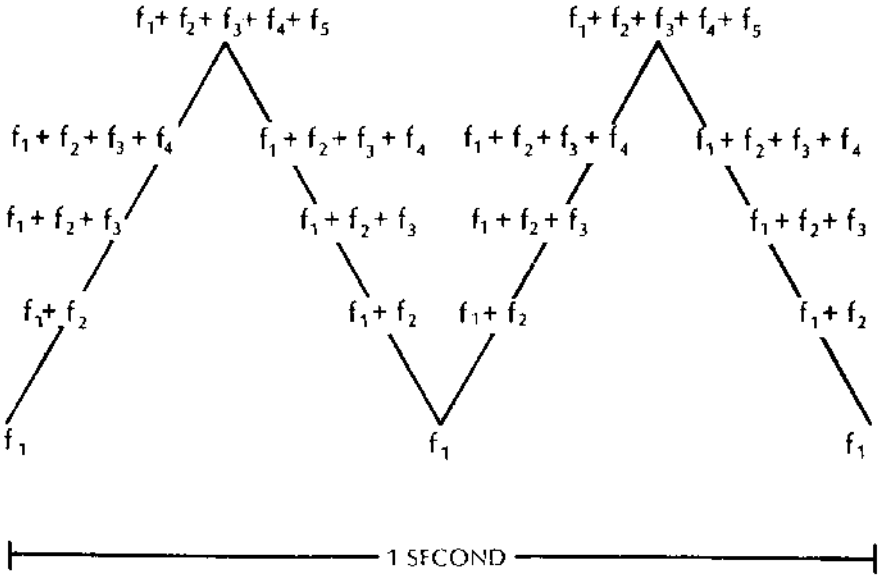


Controller functions (envelopes and the modulation oscillator) can also be applied to the filter to produce dynamic changes in timbre. As explained previously, the filter will pass certain overtones or groups of overtones present in the waveform which flowed to the filter from the oscillator. The resonance control of the filter determines the relative loudness of these overtones.

Applying a modulation oscillator to the filter is in essence identical to moving the tune control up and down. It brightens and dulls the sound by increasing and decreasing the number of overtones permitted to pass through the filter. An example of modulation of a filter is the "wha-wha" device used with electric guitars and most combo organs.

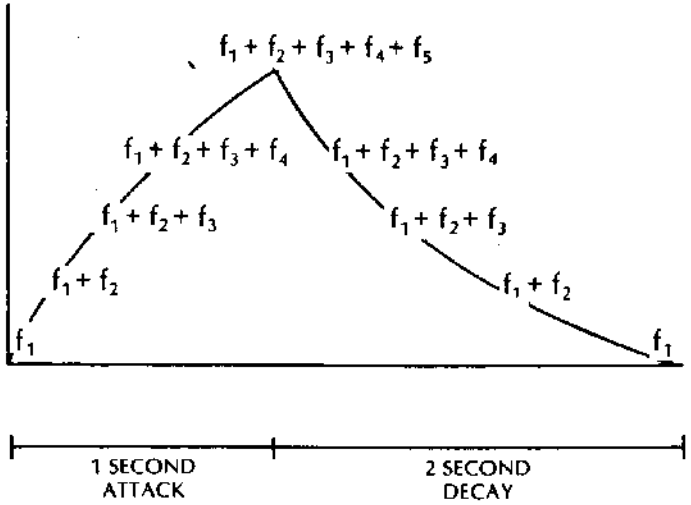
With the synthesizer, we can apply a small amount of "modulation" to the filter and get very small changes in timbre; or apply a great amount of modulation and get drastic changes in timbre. For example, let's apply a two cycle per second triangle waveform to the filter.

The filter's input oscillator is producing 440 cycles per second sawtooth waveform (even and odd overtones — $f_1, f_2, f_3, f_4, f_5, \ldots$ etc.) and is flowing into the filter. The filter's tune control is set to the first overtone (f_2) and is passing the fundamental (f_1) and the first overtone (f_2). With the modulation oscillator being applied, the timbre will start out very dull sounding and get progressively brighter as the modulation oscillator permits more and more overtones to pass through the filter to the amplitude shaper. Then the timbre will get duller as the number of overtones allowed to pass through is decreased. The overall effect is a "wha-wha." Graphically the result of a 2 cycle triangle waveform being applied to a filter set to the first overtone is shown below.



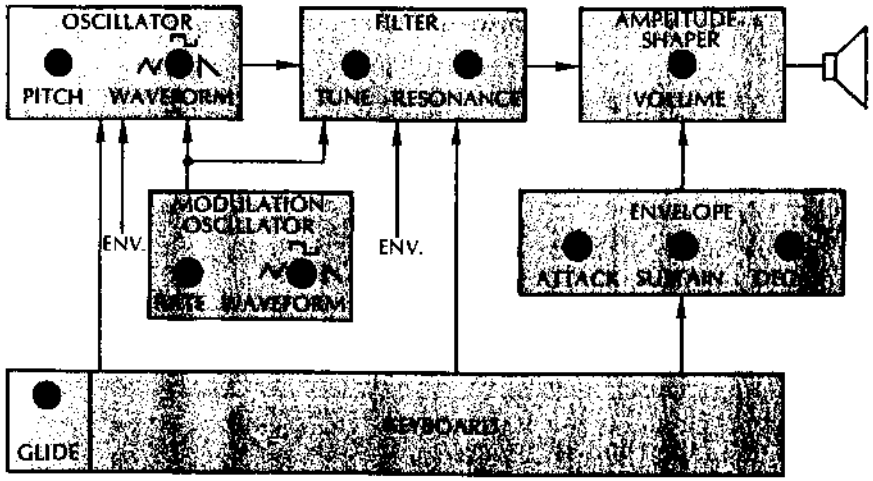
An envelope may also be used to control the filter. During the attack time, the filter will gradually "open", permitting more and more overtones to pass through to the output, brightening the sound. During decay, the filter will gradually close and fewer overtones will be permitted to pass until the filter returns to the pre-envelope condition as set by the filter's tune control. This control of the filter is called enveloping the filter or applying a "contour" to the filter.

A graph of the application of the filter to envelope to the filter is shown below.



OTHER SYNTHESIZER FUNCTIONS

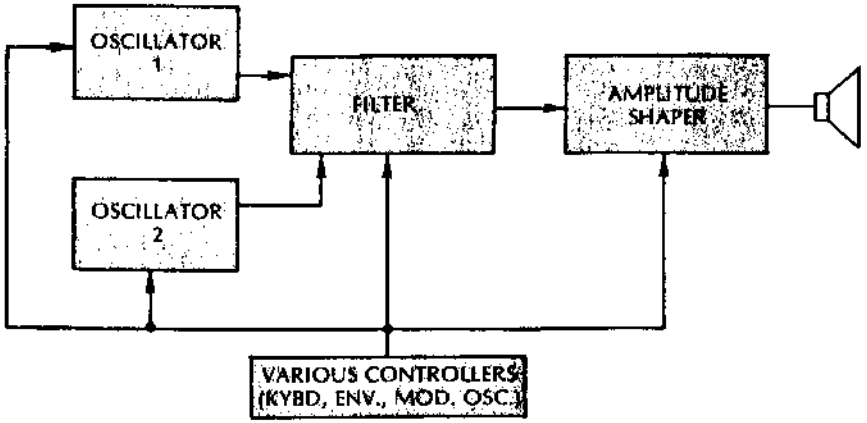
A complete block diagram of the synthesizer as described to this point appears below.



So far we have covered the major functions of a synthesizer. Of course, any of these may appear in a single synthesizer more than once. In addition, there are a number of functions not yet referred to of which you should be made aware.

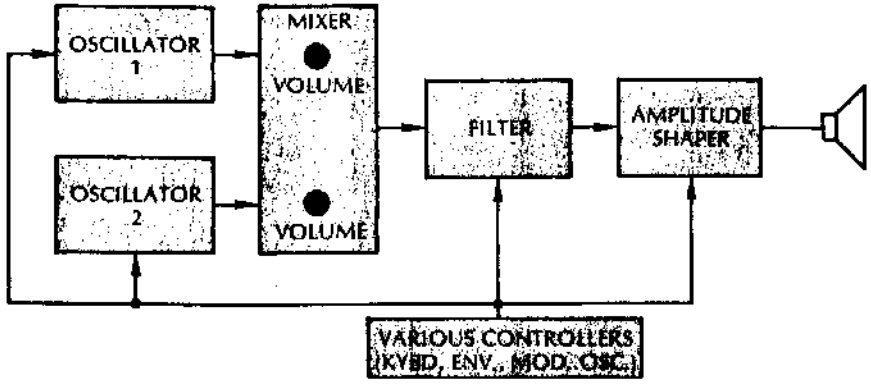
ADDITIONAL OSCILLATORS

The presence of more oscillators permits more complex audio sounds to be produced and/or provides additional control oscillators. Additional source oscillators can be tuned to musical intervals. Additional modulation oscillators mean different varieties and rates of modulation can be applied to the oscillators and filter.

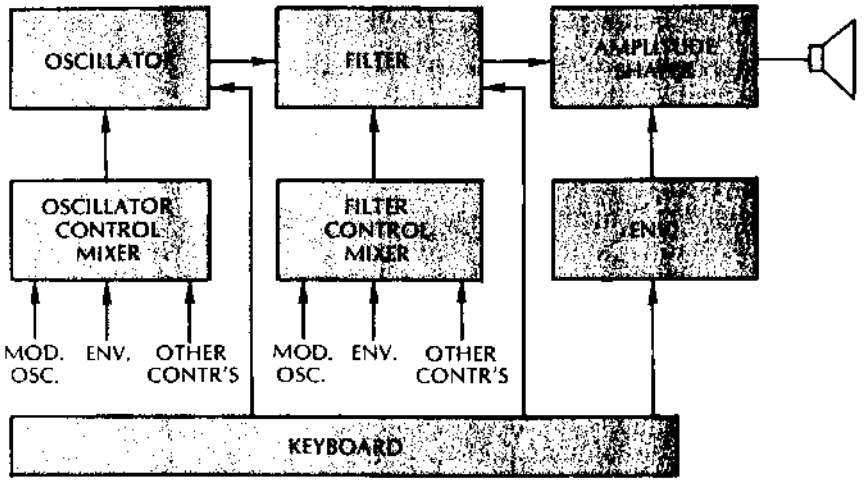


MIXERS

Normally, when there's more than one audio source or more than one control source, a mixer is used. For example, if there were two source oscillators going into the filter, a mixer would be placed between the sources and filter. This mixer permits you to independently control the volume of each source. This mixer would probably be known as the filter input mixer.

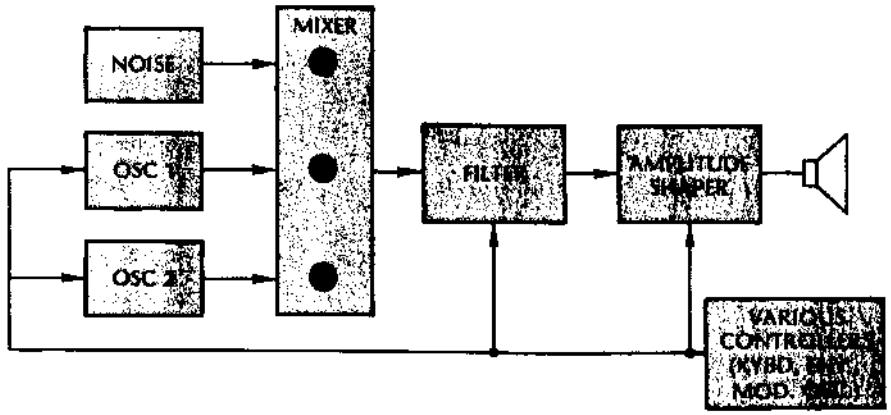


Mixers are also used to combine more than one controller function to either an oscillator or filter. For example, let us say you wish to apply both a modulation oscillator and an envelope to a source oscillator. You would then use a mixer to control the effect each controller has on the source oscillator or filter. This type of mixer is usually known as either an oscillator control mixer or as a filter control mixer.



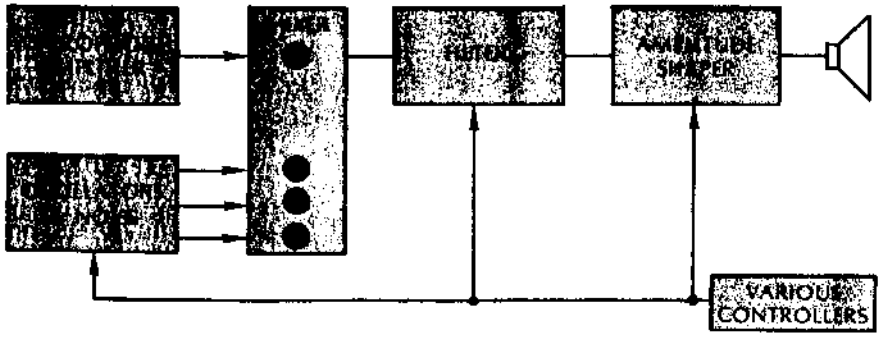
NOISE GENERATOR

A noise generator is frequently used as a sound source. Noise has no particular pitch, but rather is a combination of all pitches. It sounds similar to wind or surf. It is primarily used to produce percussive sounds.



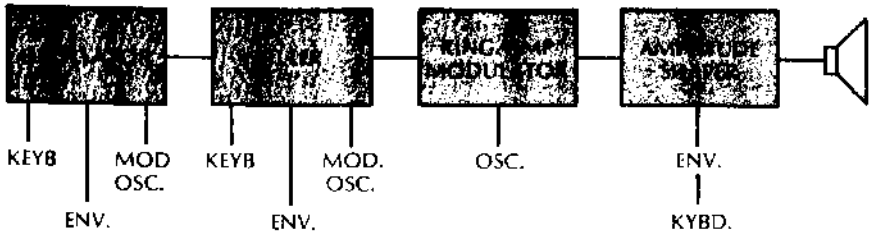
MICROPHONE AMPLIFIER

The microphone amplifier is used to introduce external sounds sources such as voices, guitars and organs to the synthesizer for subsequent modification.



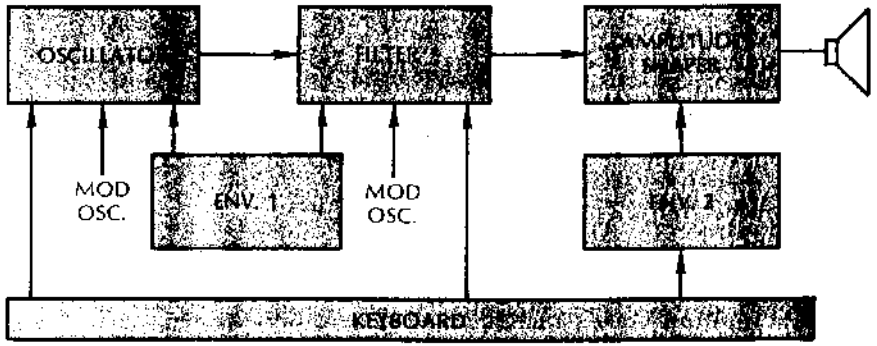
AMPLITUDE/RING MODULATOR

The amplitude/ring modulator is another control device. It provides for other changes in loudness or timbre. Some of the more common effects produced by its usage are tremolos and chimes. Using amplitude modulation we can get a desired tremolo or a strumming effect. The chimes and bell effects are produced by using the ring modulator.



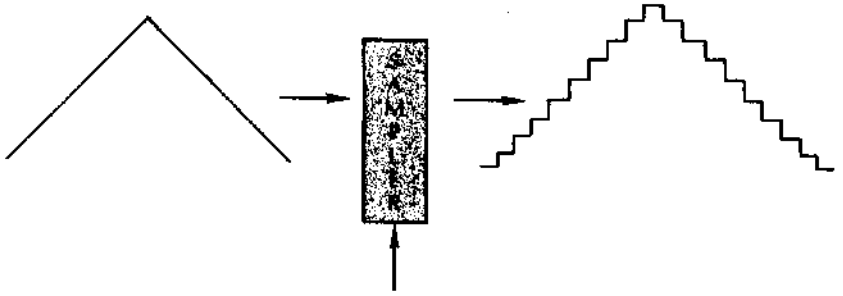
ENVELOPE GENERATOR

Additional envelopes are often provided. This permits you to vary the pitch or timbre in one way while varying the loudness in another.

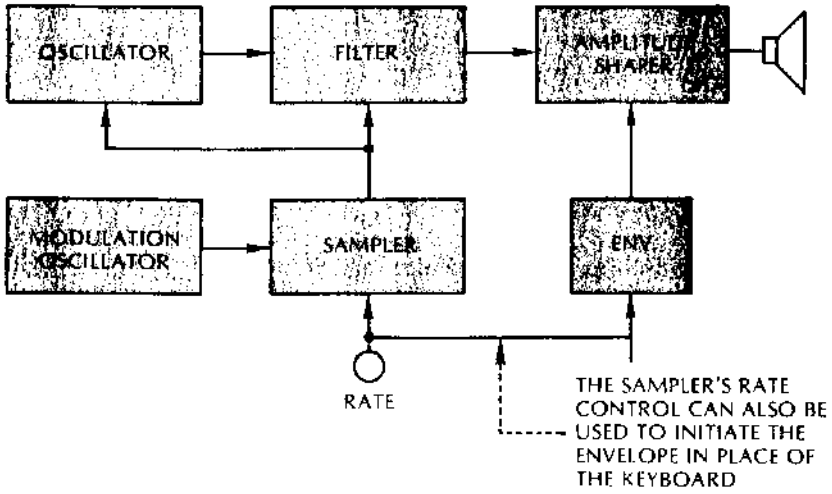


SAMPLER

The sampler is a controller that permits the generation of random or ordered patterns of notes. It normally accomplished this by transforming the output of a modulation oscillator into a staircase, as shown below.



The resultant staircase can then be applied to the oscillators or filter. Here it will produce appropriate changes in pitch and timbre. These changes can result in patterns of notes.



This concludes our discussion of the synthesizer. Of course, no attempt has been made to provide a technical understanding of its functions — maybe that's for another day.

Regardless, we hope the booklet has been educational. Your comments for improvements are welcome. And if you're ever in the area, stop in and visit our factory.